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Forest Service

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The Least Total Expected Cost

An Economic Analysis Method for Selection of Culverts and Other Transportation Structures

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Introduction

The economic analysis method covered in this document is applicable where economics is the primary consideration in the decision. The method may not be applicable where the design return frequency is set by environmental and legal considerations (i.e., fisheries and local standards).

To assure resource protection, some management policies may require that drainage structures be designed to accommodate at least a 100 year flood, including associated bed-load and debris. Designing drainage structures to withstand a specific year flood does not necessarily mean sizing the drainage structure to carry the total flow without over topping. Other means such as allowing flood water to over-top the fill may be more economical provided the fill structure can withstand the over-topping, or the fill material used can be selected such that its loss would not be detrimental to other resources. The method described in this document will assist in this consideration of alternatives as long as the alternatives address both economic and resource protection issues.

The Least Total Expected Cost (LTEC) economic analysis method is a process of optimization where engineering economic analysis of alternate designs provides a basis for decision making. The LTEC analysis method considers all costs involved in a drainage structure and provides a rational method of choosing the most economical structure. Use LTEC to:

1. perform economic evaluations of alternatives for road bridges and culverts and, where appropriate, for trail bridges;

2. develop and evaluate alternatives that meet road, resource, and ecosystem management objectives (FSH 7709.56b, sec. 1.11, and FSM 7712.3); and

3. develop and evaluate alternatives for trail bridges that meet the intended use of the trail.

Definitions

Annual Peak Flood. The maximum flow occurring during the year.

Annual Risk Cost. Product of the probability of an event and the cost of damages caused by that event.

Exceedance Probability. Probability that a given flood discharge will be equaled or exceeded within a certain period of time, usually 1 year. It is expressed either as a decimal or percent.

Flood Damage Costs. The costs to repair or restore all structures, roads, trails, channels, property, and any natural resources damaged during the flood.

Incremental Probability. For a given range of floods, such as those between the 5- and 10-year floods, the incremental probability is the probability that the annual peak flood for any 1 year is greater than the smaller flood (5-year), but less than the larger flood (10-year).

Recurring Costs. Costs that continue to occur over a period of time.

Return Period. The period, Tr (number of years), on the average that a flood will be equaled or exceeded. For example, a flood with a return period of 100 years will be equaled or exceeded on the average of once every 100 years.

Simplifying Assumptions. Assumptions that are not strictly true in all cases, but will simplify calculations without introducing unacceptable errors.

Total Structure Capital First Cost. Preconstruction and construction costs, including all associated overhead.

Traffic Related Costs. Costs incurred because vehicles cannot reach their destination, such as costs to take detours because of flood damage and costs to construct or improve detours.

Economic Analysis of Alternatives

Use the LTEC analysis method described in the Federal Highway Administration publications listed in the References section. Examples 1 through 3 and figures 3 and 4 show examples of LTEC methods that analyze and compare alternatives for both culverts and bridges. Additional guidance on the use of these examples is provided throughout this publication.

Use professional judgment to determine the extent of the LTEC analysis. Match the extent of the analysis with the cost of the structure and the cost of the expected flood damage that can be associated with the structure.

Information Required for LTEC Analysis

Use the following procedures and given information to make calculations for the LTEC analysis:

1. Economic period (FSH 7709.56b, sec. 7.4). Typically use a 50-year economic period/life for road structures. Plan for replacement of materials that wear out within that time frame.

2. Interest rate. Use the rate prescribed in FSH 1909.17, chapter 10. As a minimum, check sensitivity using the rate prescribed in OMB Circular A-94.

3. Total structure capital first cost.

4. Recurring costs. Estimate maintenance, operation, and any other recurring costs on an annual basis.

5. Flood discharge and frequency values. Develop several frequencies and their corresponding peak discharges for the project site, usually the 2-, 5-, 10-, 25-, 50- and 100-year floods (FSH 7709.56b, chap. 5). Do not use a single arbitrary flood frequency. See "The Design of Encroachments on Flood Plains Using Risk Analysis" (FHWA HEC-17) for additional information.

6. Flood damage costs. Use the hydraulic analysis data (FSH 7709.56b, sec. 6.22) to estimate these costs and to determine the backwater profile, headwater depth, overtopping depth, and outlet velocity for each flood magnitude considered. Ignore flood damage costs that would be incurred if the structure did not exist.

7. Traffic related costs.

Determine the design flood frequency by finding the most economical structure, rather than using an arbitrary design flood frequency.

For each alternative structure type, pick two or three sizes to analyze and determine the total expected cost (TEC) for each alternative as follows:

1. Calculate total annual capital costs for each size of each alternative structure type. Reduce capital first costs to annual costs using the economic period and interest rate (see "Information Required for LTEC Analysis," above). Add the annual capital costs to the annual recurring maintenance costs. If the recurring costs are the same for all alternatives, do not include them in the calculation.

   The resulting total is the annual capital cost that will be incurred whether or not the drainage structure is damaged by floods.

2. Convert flood damage and traffic losses to annual risk costs as follows:

   a. Sum the flood damage and traffic related costs for each selected return period flood.

   b. Arrange the return periods and damage costs into ranges such as 2 to 5 years and 5 to 10 years.

   c. Calculate the annual probability of a flood whose return period is within each range (FSH 7709.56b, sec. 5.2). This is the incremental probability.

   d. Calculate the average damage cost for each flood range.

   e. Multiply the average estimated damage cost for each range by the incremental probability to find the incremental risk cost.

   f. Sum the incremental risk costs to find the total annual risk cost for the alternative.

3. Add the total annual capital costs and the total annual risk costs to find the annual (TEC) for each size of each alternative structure type.

4. Compare all alternatives to determine the one with the LTEC. Plot the risk, total annual capital costs, and total expected costs versus return period for sensitivity analysis.

Simplifying Assumptions

If information for making a detailed analysis is not available, make simplifying assumptions. For example, the most difficult part of the LTEC process is estimating the damage cost for floods of different magnitudes and return periods. The most extreme situation would be that the entire structure and embankment would be lost during any flood above a certain magnitude. Although this is seldom the case, making this assumption would give a conservative result and a more rational design than using an arbitrary design flood frequency such as the 50-year or 100-year flood. Therefore, when appropriate, use this simplifying assumption in calculating the LTEC.

Other simplifying assumptions may be used in accordance with Regional guidance.

Examples of LTEC Analysis

See example 1 for an LTEC example for minor culverts and example 2 for an LTEC example for bridges and major culverts. Figures 1 and 2 and example 3 are illustrations and examples of calculations needed for the LTEC procedures.

Example 1.—Example of Least Total Expected Cost (LTEC) Analysis (Culverts) :

I. *Situation.* The designer wishes to determine the most economical size of round corrugated metal pipe to cross a small stream. The fill height will be 10 feet (3 m) above the inlet invert of the pipe.

The fill will be level for 100 feet (30 m), roughly 50 feet (15 m) each side of the culvert. Gravel surfacing cost for the level 100-foot (30 m) section is $500.

The pipe will be 55 feet (16.8 m) long, step beveled, with a reinforced entrance.

II. *Information Required for the LTEC Analysis.*

1. Economic period is 50 years.

2. Interest rate is 4 percent; check sensitivity at 10 percent. (FSH 1909.17; 15.42–Recommended Discount Rates)

3. Total capital first cost of the structure. Consider only installed culvert costs because preconstruction costs and the construction costs for the fill and gravel surfacing will be the same for all culvert sizes.

Pipe Size (inches)	Installed Cost (dollars)
36	$1,600
42	2,100
48	2,500
54	2,900
60	3,300
66	3,800
72	4,700
78	5,300

4. Recurring maintenance costs. Do not include recurring maintenance costs in the analysis because they are the same for all culvert sizes.

5. Flood discharge and frequency values.

Return Period (years)	Discharge (cfs)	Exceedance Probability
2	25	0.5
5	73	0.2
10	136	0.1
25	250	0.04
50	362	0.02
100	485	0.01

6. Flood damage costs. Assume the culverts will not fail because of inlet failure or clogging with debris. Base flood damage costs on the overtopping depth and the assumption that there is no upstream flood damage due to backwater. See exhibit 02, FSH 7709.56b, sec. 6.45q, for the method to determine the overtopping design flood depth.

   For each culvert being evaluated, prepare a table of flood damage losses for each culvert size. The following table shows flood damage losses for the 54-inch culvert. The maximum damage for the 54-inch culvert ($5,400) includes $2,900 for culvert installation and $2,500 for gravel and fill loss. The maximum gravel and fill loss ($2,500) was used for all the other alternative sizes.

54-Inch Culvert

Return Period (Tr) (years)	Exceedance Probability	Overtopping Depth (feet)	Flood Damage Losses
15	0.067	0.0	$ 0
25	0.040	0.4	500
50	0.02	0.7	2,500
100	0.01	1.0	5,400

7. Traffic related costs. Negligible at this site.

III. *Conducting the LTEC Analysis.*

Method A:

1. Calculate total annual capital costs. For example, calculate total annual capital costs as follows:

   To calculate the total annual capital cost for the 54-inch culvert, use the Capital Recovery Factors (CRF) at 4 percent and 10 percent interest rates for 50 years. (CRF, 4 percent, 50 years) = 0.04655; (CRF, 10 percent, 50 years) = 0.10086

   Total annual capital cost:

   Using 4 percent interest = $2,900 x 0.04655 = $135
   Using 10 percent interest = $2,900 x 0.10086 = $292

2. Convert flood damage losses to total annual risk costs. The following table shows calculations of the total annual risk cost for the 54-inch culvert.

Return Period	Exceedance Probability	Losses	Average Losses	Incremental Probability	Incremental Risk Cost
15	0.067	$ 0			
			$ 250 x	0.027 =	$ 7
25	0.04	500			
			1,500 x	0.02 =	30
50	0.02	2,500			
			3,950 x	0.01 =	40
100	0.01	5,400			
			5,400 x	0.01 =	54
Infinite	0.0	5,400			
			Total annual risk cost	=	$ 131

Example 1.—Continued

3. Add the total annual capital cost and the total annual risk cost to find the annual total expected cost for each culvert size. These costs are summarized in the following tables for the alternatives:

Culvert Size (inches)	Total Annual Capital Cost Using: 4%	10%	Total Annual Risk Cost	Total Expected Cost (TEC) Using: 4%	10%
36	$ 75	$161	$313	$388	$474
42	97	211	245	342	456
48	117	251	179	296	430
54	135	292	131	266	423
60	154	332	106	260	438
66	177	382	98	275	480
72	219	473	87	306	560
78	247	535	78	325	612

4. Compare all total expected costs (TEC) to determine the alternative with the LTEC. Using a 4 percent interest rate, the LTEC design alternative is the 60-inch culvert, but there is very little difference ($6) in the TEC's for the 60- and 54-inch culverts, so either size would be acceptable at that interest rate. At 10 percent interest, the 54-inch culvert is the LTEC design alternative. The design choice is the 60-inch culvert using the Forest Service Rate of 4 percent, but either the 54-inch or 60-inch could be acceptable.

   Use the illustrations in figures 1 and 2 to determine that the design overtopping flood return period is 15 years for the 54-inch culvert and 21 years of the 60-inch culvert.

   Calculations can be simplified by assuming that any flood greater than the overtopping design flood will cause maximum damage to the surfacing and fill, and completely destroy the culvert. This conservative assumption increases the culvert size of the LTEC alternative.

Method B:

The following example uses a simplified method:

1. Determine the annual probability of overtopping for each culvert size. For example, the 54-inch culvert is overtopped by any flood greater than the 15-year flood as shown in the illustrations in figures 1 and 2. Therefore, the annual probability of overtopping is 1/15 = 0.067.

2. Determine the total annual risk cost for each culvert size. For the 54-inch culvert it is 0.067 x $5,400 = $362.

3. From step 3 in the above example, determine the total annual capital cost for each culvert size. For the 54-inch culvert, total annual capital cost is $135 at 4 percent and $292 at 10 percent.

Example 1.—Continued

4. Add the total annual risk cost and the total annual capital cost to find the annual for each size of culvert. For the 54-inch culvert, the annual TEC is $497 at 4 percent, and $654 at 10 percent.

5. The total annual risk costs, total annual capital costs, and annual TEC's for other culvert sizes, calculated in a similar manner, are as follows:

Culvert Size (inches)	Total Annual Capital Cost Using: 4%	10%	Total Annual Risk Cost	Total Expected Cost (TEC) Using: 4%	10%
36	$ 75	$ 161	$697	$772	$858
42	97	211	506	603	717
48	117	251	450	567	701
54	135	292	362	497	654
60	154	332	278	432	610
66	177	382	239	416	621
72	219	473	194	413	667
78	247	535	170	417	705

Using the simplified method resulted in the 66- to 72-inch culverts being the alternatives with the LTEC with a 4 percent interest rate, while at 10 percent the 60-inch culvert had the LTEC.

Note: The TEC curve is quite flat at 4 percent for 60-inch through 78-inch culverts. Based on the conservative assumption used, the minimal TEC difference between the 60-inch, and 66-inch, 72-inch, and 78-inch culverts at 4 percent interest, and the choice of a 60-inch culvert at 10 percent interest, the 66-inch culvert is a logical design selection. Using the simplifying assumption resulted in selecting a culvert two sizes larger.

The design overtopping flood return period for the 60-inch culvert is 21 years, while it is 26 years for the 66-inch culvert. See figures 1 and 2 for illustrations for determining return periods from head water depths and discharge values. See the illustration in exhibit 02, FSH 7709.56b, sec. 6.45q, for the method to determine overtopping design flood overtopping depth.

Example 2.—Example of Least Total Expected Cost (LTEC) Analysis (Bridges and Major Culverts)

I. *Situation.* A planned road must cross a stream and adjacent flood plain. The Forest wildlife specialist determined that the stream is an important trout fishery and has requested that the channel bottom remain in a natural condition.

A foundation investigation indicates that the stream bottom consists of 3 feet (0.9 m) of gravel and cobble over solid rock.

The designer decided that a cast-in-place concrete bridge with spread floodings or a metal arch culvert on concrete footings will best fit the site conditions and requirements and selected nine alternative bridge sizes and five alternative culvert sizes for comparison.

The approach embankments are to be kept low enough so they will fail before the structure is endangered. Because of geometric constraints, the maximum allowable flood plain fill height is 8 feet (2.4 m), which is 2 feet (0.6 m) below the bridge deck for a 16-foot (4.9 m) abutment. All culverts use the maximum allowable food plain fill height of 8 feet (2.4 m) to maximize the hydraulic capacity.

Because the footings will be on rock, the structure will not fail as a result of scour. Thus the only damage from floods will be to the road surfacing (gravel) and the embankments. Assume that once the embankments are overtopped and the maximum damage will occur to them and to the gravel surfacing. Backwater from the structure will cause no upstream damage and traffic interruption costs will be negligible.

II. *Information Required for the LTEC Analysis.*

1. Economic period is 50 years.

2. Interest rate is 4 percent; check sensitivity at 10 percent. (FSH 1909.17; 15.42–Recommended Disocunt Rates).

3. Total capital first cost of the structures. Preconstruction cost differences between alternatives are negligible and are therefore not included.

   a. *Cast-in-place concrete bridges.*

Alternatives	Span Length (feet)	Abutment Height (feet)	Flood Plain Fill Height (feet)	Structure Cost	Fill and Gravel Cost	Total Capital First Cost
1	20	12	4	$29,600	$3,800	$33,400
2	20	14	6	35,100	6,000	41,100
3	20	16	8	42,600	8,600	51,200
4	25	12	4	32,600	3,800	35,800
5	25	14	6	37,500	6,000	43,500
6	25	16	8	45,000	8,600	53,600
7	30	12	4	34,400	3,800	38,200
8	30	14	6	39,900	6,000	45,900
9	30	16	8	47,400	8,600	56,000

Example 2.—Continued

b. *Metal arch culverts.*

Size	Flood Plain Fill Height (feet)	Culvert Cost	Slope Paving Cost	Footing Cost	Fill and Gravel Cost	Total Capital First Cost
16' x 8'3"	8	$ 9,000	$3,000	$8,000	$8,600	$28,600
18' x 8'11"	8	10,500	3,000	8,000	8,600	30,100
20' x 10'	8	13,000	3,000	8,500	8,600	33,100
23' x 9'10"	8	14,000	3,000	8,500	8,600	34,100
25' x 10'	8	15,500	3,000	9,000	8,600	36,100

4. Recurring maintenance costs. Do not include recurring maintenance costs in the analysis. These costs were determined to be essentially the same for all alternatives.

5. Flood discharge and frequency values. Using the appropriate method for the site, the following discharges were calculated for the indicated return periods.

Return Period (years)	Discharge (cfs)
5	900
10	1,150
25	1,500
50	1,800
100	2,000

Using the preceding data, a flood magnitude versus return period curve was prepared for the site as discussed in FSH 7709.56b, section 5.3; however, the curve is not included in this figure. The flood magnitude versus return period curve and performance curves shown in figures 1 and 2 are for the example in example 1 only.

6. Flood damage costs. Based on the assumption that the structure will not be damaged by any flood and the simplifying assumption that the entire fill and gravel surfacing will be lost when the fill is overtopped, the flood damage costs are the original fill and gravel costs for each alternative.

7. Traffic related costs. Negligible at this site.

III. *Conducting the LTEC Analysis.*

1. Calculate total annual capital costs by multiplying the total capital first cost by the appropriate capital recovery factor (CRF) using 4 percent and 10 percent interest rates for 50 years. (CRF, 4 percent, 50 years) = 0.04655; (CRF, 10 percent, 50 years) = 0.10086. For bridge alternative 1, the total annual capital cost is:

Using 4 percent interest = $33,400 x 0.04655 = $1,555
Using 10 percent interest = $33,400 x 0.10086 = $3,369

The annual capital costs for the other alternatives are calculated similarly.

Example 2.—Continued

2. Calculate the total annual risk costs. In this example, to find the total annual risk costs, multiply the fill and gravel costs by the annual probability of overtopping.

   To find the annual probability of overtopping, prepare a performance curve for each alternative (FSH 7709.56b, sec. 6.45). From the performance curve, determine the discharge that just causes embankment overtopping (FSH 7709.56b, sec. 6.45).

   Use the "HY-7, Bridge Waterways Analysis model, Micro Computer Software" (FHWA) (FSH 7709.56b, sec. 6.08b) to develop the performance curve for each alternative bridge design. For arch culverts use "Hydraulic Design of Highway Culverts" (FHWA HDS-5), and/or "HY-8, FHWA Culvert Analysis" (FSH 7709.56b, sec. 6.08b) computer software to develop a performance curve for each culvert. These curves are not included in this figure.

   For each alternative, find the overtopping return period (Tr) from the flood magnitude versus return period curve in figure 1, using the design overtopping discharge for that alternative.

   The annual probability of overtopping is the reciprocal of the design overtopping return period (1/Tr).

The annual risk cost calculations are summarized as follows:

a. *Cast-in-place concrete bridges.*

Alternative	Overtopping Return Period (Tr) (years)	Annual Probability of Overtopping (1/Tr)		Fill and Gravel Overtopping Damage		Total Annual Risk Cost
1	2	0.5	x	$3,800	=	$1,900
2	8	0.125	x	6,000	=	750
3	30	0.033	x	8,600	=	284
4	3	0.33	x	3,800	=	1,254
5	15	0.067	x	6,000	=	402
6	100	0.01	x	8,600	=	860
7	4	0.25	x	3,800	=	950
8	24	0.042	x	6,000	=	52
9	120	0.008	x	8,600	=	69

Example 2.—Continued

b. *Metal arch culverts.*

Size	Overtopping Return Period (Tr) (years)	Annual Probability of Overtopping (1/Tr)	Fill and Gravel Overtopping Damage	Total Annual Risk Cost
16' x 8'3"	7	0.143	x $8,600	= $1,230
18' x 8'11"	11	0.091	x 8,600	= 783
20' x 10'	25	0.04	x 8,600	= 344
23' x 9'10"	40	0.025	x 8,600	= 215
25' x 10'	75	0.013	x 8,600	= 112

3. Add the total annual capital cost and the total annual risk cost to find the annual TEC for each alternative. These costs are summarized as follows:

a. *Cast-in-place concrete bridges.*

Alternative	Total Annual Capital Cost Using: 4%	10%	Total Annual Risk Cost	Total Expected Cost (TEC) Using: 4%	10%
1	$1,555	$3,369	$1,900	$3,455	$5,269
2	1,913	4,145	750	2,663	4,895
3	2,383	5,164	284	2,667	5,448
4	1,666	3,611	1,254	2,920	4,865
5	2,025	4,387	402	2,427	4,789
6	2,495	5,406	860	3,355	6,266
7	1,778	3,853	950	2,728	4,803
8	2,137	4,629	252	2,389	4,881
9	2,607	5,648	69	2,676	5,717

b. *Metal arch culverts.*

Size	Total Annual Capital Cost Using: 4%	10%	Total Annual Risk Cost	Annual Total Expected Cost (TEC) Using: 4%	10%
16' x 8'3"	$1,331	$2,885	$1,230	$2,561	$4,115
18' x 8'11"	1,401	3,036	783	2,184	3,819
20' x 10'	1,541	3,338	344	1,885	3,682
23' x 9'10"	1,587	3,439	215	1,802	3,654
25' x 10'	1,680	3,641	112	1,792	3,753

Example 2.—Continued

4. Compare all annual TEC's to determine the alternative with the least annual TEC.

   a. *Cast-in-place concrete bridges.* At 4 percent interest, alternative 8 with a 24-year overtopping frequency has the least annual TEC. Alternative 5 with a 15-year overtopping frequency has only a slightly higher TEC.

      At 10 percent interest, alternative 5 has the least annual TEC but alternative 7 is close to the least annual TEC, but the overtopping return period is only 4 years. The high frequency at which embankment material would be washed into the stream and the road closed for repairs makes alternative 7 unattractive.

      Based on a 4 percent interest rate, either alternative 5 or 8 would be acceptable. Alternative 5 would be favored because its annual TEC at 10 percent is still the least annual TEC. But, from an overtopping frequency standpoint, alternative 8 appears more attractive. Also, the initial cost of alternative 8 is only slightly higher than alternative 5. From a bridge standpoint, the decision is to select alternative 8.

   b. *Metal arch culverts.* At a 4 percent interest rate, the 25- by 10-foot arch culvert with a 75-year overtopping frequency has the LTEC with a slight advantage over the 23- by 9-foot, 10-inch arch. At a 10 percent interest rate, the 23-foot by 9-foot, 10-inch arch culvert with an overtopping frequency of 40 years has the least annual TEC ahead of the 20- by 10-foot arch and the 25- by 10-foot arch.

   c. *Design selection.* Because the annual TEC of the 23- by 9-foot 10-inch or the 25- by 10-foot arch culverts are much lower than that of the bridge alternatives, they are reasonable design choices for this site.

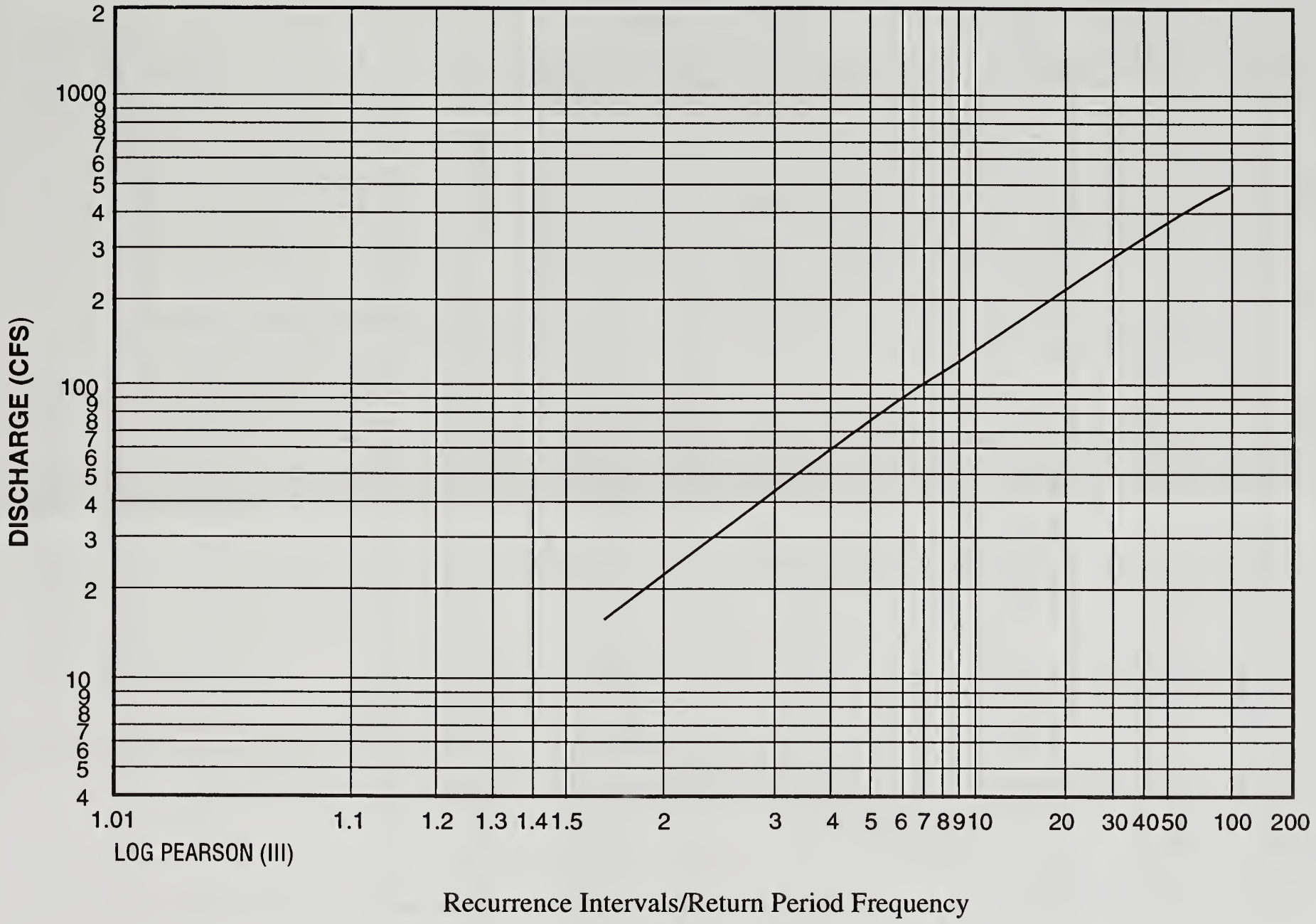

Figure 1.—Discharge Versus Recurrence Interval Curve (FSH 7709.56b, sec. 5).

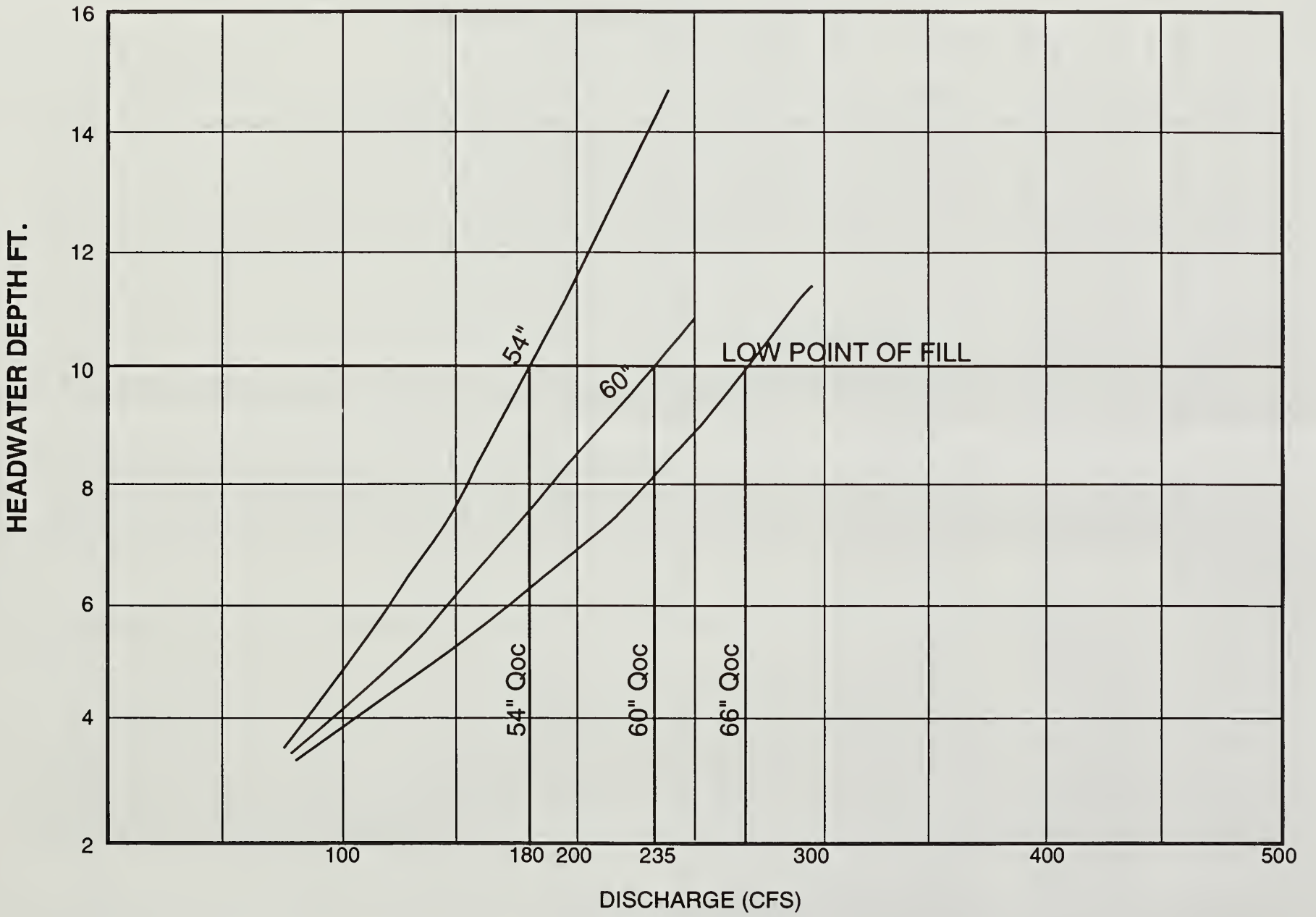

Figure 2.—Culvert Performance Curves (FSH 7709.56b, sec. 6.45).

Example 3.—Calculating the appropriate Return Period Flood Frequency for a Class of Culverts

I. *Situation.* The Forest wishes to find an appropriate design return period for a class of culverts for stream crossings in drainage areas of 1/3 square mile (0.86 km^2, 86 Ha) or less in a particular geographic area. Culverts will be of round corrugated metal, have a projecting inlet, and have fill heights up to 6 feet (1.8 m). Base the design return period on an LTEC analysis.

II. *Process.* Use representative sites from the geographic area and, where available, use actual repair cost data. In this example, assume that overtopping causes the maximum fill and surfacing damage and the loss of the culvert.

Site	Fill Height (feet)	Drainage Area (square mile)	Maximum Fill and Surfacing Damage
1	6.0	0.20	$1,000
2	5.0	0.10	500
3	5.5	0.15	750
4	6.0	0.30	1,000
5	4.5	0.20	500
6	6.0	0.10	1,000

1. Calculate the optimum return period flood for each site as described here for site number 1:

   a. Try a 30-inch diameter corrugated metal pipe, 35 feet (10.7 m) long, costing $850.

   b. Construct the performance curves and the flood discharge magnitude versus return period curve for this situation. See FSH 7709.56b, section 6.45q, on how to prepare the performance curves. Curves in figures 1 and 2 are not valid for this situation, but are illustrations of similar curves.

   c. From the performance curve for 30-inch corrugated metal pipe developed in paragraph b., the overtopping design discharge for headwaters 6 feet deep is 40 cfs.

   d. From the flood magnitude versus return period curve developed in paragraph b., select the return period (Tr) for a discharge of 40 cfs, which is 7 years.

   e. Determine the probability (p) of the 7-year flood being equaled or exceeded each year: (p) = 1/Tr = 1/7 = 0.14.

   f. Determine the total annual capital cost for the culvert (see "LTEC Procedures," above):

   (Capital Recovery Factor, 4 percent, 50 years) = 0.04655
   (Capital Recovery Factor, 10 percent, 50 years) = 0.10086

   Using 4 percent interest = $850 x 0.04655 = $40
   Using 10 percent interest = $850 x 0.10086 = $86

g. Determine the total annual risk cost for the culvert (see "LTEC Procedures," above):

(0.14 x ($1,000 + $850)) = $259

h. Add the total annual capital cost and total annual risk cost to get the Total Expected Cost (TEC).

TEC = $40 + $259 = $299 using 4 percent interest rate.
TEC = $86 + $259 = $345 using 10 percent interest rate.

i. Repeat steps a through g for a 36-, 42-, and 48-inch culvert. Summarize the results for all culvert sizes as follows:

Culvert Size (inches)	Overtopping Return Period (Tr) (years)	TEC Using: 4%	10%
30	7	$299	$345
36	12	224	272
42	17	201	300
48	25	205	310

Using 4 percent interest rate, the LTEC culvert size is 42 inches and the optimum return period is 17 years. At 10 percent interest rate, the LTEC culvert size is 36 inches with a 12-year optimum return period.

j. Calculate the optimum return periods for the five other sites. The following table summarizes this information:

Site	LTEC Return Period in Years Using: 4%	10%
1	17	12
2	10	7
3	12	9
4	15	12
5	12	8
6	20	15

2. Using a 4 percent interest rate, the average return period is 14.3 years, while at 10 percent, the average return period is 10.5 years. Select the design return period based on the availability of maintenance funds, sensitivity of streams to sediment, and public concerns.

With a 10 percent interest rate, a 15-year design return period is probably the maximum that can be justified. The 15-year period provides a larger culvert than is called for in the LTEC analysis for 83 percent of the sites in the class. With a 4 percent interest rate, a 15-year design return period will provide a culvert as large or larger than called for in the

Example 3.—Continued

LTEC analysis for 67 percent of the sites in the class. Therefore, a design return period of 15 years is a reasonable selection in this geographic area where fill height is no more than 6 feet (1.8 m), drainage area is 1/3 square mile (0.86 km^2, 86 Ha) or less, and repair costs do not exceed $1,000.

Since most hydrology methods do not give 15-year flood discharge values, plot the 5-, 10-, 25-, and 50-year flood discharge values and interpolate the 15-year flood magnitude value from the curve. See the example in section 5.2 (ref. 4) for procedures to determine this flood discharge value.

The larger the number of sites and the number of class groupings within the total number of sites, the more economical the resulting design return period will be.

The LTEC method generally results in using smaller culverts than have traditionally been used. Check the outlet velocities for small culverts with high fills that should be considered in the LTEC analysis because the high velocities may cause damage. Decide whether energy dissipation measures are needed that would increase the initial cost.

Alternative to Individual Site LTEC Analysis

It is not necessary to make an LTEC analysis on every structure built on National Forest System land. Within a geographical area where construction and repair costs are similar, place structures in classes and analyze them as a group to find the appropriate return period flood for that class. This is especially appropriate for small culverts. For example, all culverts on a particular Ranger District for drainage areas of 1/3 square mile (0.86 km^2, 86 Ha), or less, with no headwall (projecting inlet) and with less than 6 feet (1.8 m) fill height, could be a class.

To find the optimum culvert class design return period, make an LTEC analysis on several typical culvert sites that fit into the class. See example 3 for an example. Follow a similar procedure to find the optimum bridge design.

Use the optimum size culvert to calculate the optimum design discharge (FSH 7709.56b, sec. 6.11). Convert the optimum design discharge into a return period by using a magnitude versus frequency curve. See figure 1 for an illustration of a discharge magnitude versus recurrence interval/ return period curve.

If the range of optimum return periods for the several sites is large, subdivide the class. For instance, use 18- to 36-inch diameter and 42- to 48-inch diameter culverts or different fill heights. If the range of optimum return periods is small for the class, use a return period that best represents the optimum return periods for the class. For example, if the range of optimum return periods is 18 to 27 years, use a 25-year flood frequency as the most appropriate design return period for the class. The 25-year flood frequency is convenient to calculate, as are the 5-, 10-, 50-, and 100-year floods.

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